Carbon dioxide elimination during high-frequency jet ventilation for rigid bronchoscopy

Biro, P ; Layer, M ; Wiedemann, K ; Seifert, Burkhardt ; Spahn, D R

Abstract: Oxygen saturation and carbon dioxide values should be monitored during high-frequency jet ventilation (HFJV). Modern transcutaneous PCO2 (PtcCO2) measurement allows the estimation of ventilation efficiency. We studied how tests of lung function could predict carbon dioxide elimination during HFJV. Lung function tests from 180 adult patients undergoing rigid bronchoscopy were analysed as factors affecting carbon dioxide elimination. The lung function test results showed a significant relationship with the efficiency of carbon dioxide elimination; the greatest impairment of carbon dioxide elimination was found in patients with combined abnormalities of lung function. Further factors associated with difficult carbon dioxide elimination were male gender and elevated body weight. Of the patients investigated, 72% had normal carbon dioxide elimination, whereas in 23% hypercapnia could be avoided only by increasing the driving pressure. The prevalence of abnormal preoperative lung function test results predicts (sensitivity 76%, positive predictive value 27%) impaired carbon dioxide elimination during jet ventilation and rigid bronchoscopy.

DOI: https://doi.org/10.1093/bja/84.5.635

Originally published at:
Biro, P; Layer, M; Wiedemann, K; Seifert, Burkhardt; Spahn, D R (2000). Carbon dioxide elimination during high-frequency jet ventilation for rigid bronchoscopy. British Journal of Anaesthesia, 84(5):635-637.
DOI: https://doi.org/10.1093/bja/84.5.635

Table 1 Baseline ECG measurements, baseline mean arterial pressure and cardiac response to intravenous adenosine 112 μg kg^{-1} before and during 1% isoflurane anaesthesia. Values are mean (SD). *Two patients did not develop adenosine-induced PR prolongation while awake, and these two patients, together with a third, did not develop it during anaesthesia. Paired *t* tests were therefore performed only on data from the 13 patients with PR prolongation both before and during anaesthesia

	Before anaesthesia	During anaesthesia	*P* value
Baseline PR interval (ms)	177 (25)	166 (24)	0.007
Baseline PP interval (ms)	1067 (168)	1099 (253)	0.546
Baseline mean arterial pressure (mm Hg)	88 (11)	76 (9)	0.003
Time to onset of PR prolongation in 13 patients (s)*	9.9 (3)	12.8 (5)	0.032
Duration of PR prolongation in 13 patients (s)*	10.1 (3)	10.1 (4)	0.595
Total number of non-conducted P waves	27	12	0.016
Minimum PP interval after adenosine (% of baseline)	75 (8)	87 (6)	0.001

the direct cardiac effects of an intravenous bolus of adenosine. This could reflect anaesthesia-induced sympatholysis.

The attenuation of the atrioventricular blocking effect of adenosine shown in this study is a consideration when an anaesthetized patient develops supraventricular tachycardia. A standard intravenous adenosine 3, 6, 12 mg regimen without additional higher doses is currently recommended. We suggest that, for the anaesthetized patient, the current maximum dose presented above needs to be reviewed.

References

1 DiMarco JP, Sellers TD, Berne RM, West GA, Belardinelli L. Adenosine: electrophysiologic effects and therapeutic use for terminating paroxysmal supraventricular tachycardia. *Circulation* 1983; **68**: 1254–63

2 Hillel Z, Thys DM. Electrocardiography. In: Miller RD, ed. *Anesthesia*. New York: Churchill Livingstone, 1994; 1241

3 Ellenbogen KA, Thames MD, DiMarco JP, Sheehan H, Lerman BB. Electrophysiological effects of adenosine in the transplanted human heart: evidence of supersensitivity. *Circulation* 1990; **81**: 821–8

4 Moser GH, Schrader J, Deussen A. Turnover of adenosine in plasma of human and dog blood. *Am J Physiol* 1989; 256: C799–806

5 Biaggioni I, Killian T, Mosquedo-Garcia R, Robertson RM, Robertson D. Adenosine increases sympathetic nerve traffic in humans. *Circulation* 1991; **83**: 1668–75

British Journal of Anaesthesia **84 (5)**: 635–7 (2000)

Carbon dioxide elimination during high-frequency jet ventilation for rigid bronchoscopy

P. Biro[1*], M. Layer[2], K. Wiedemann[2], B. Seifert[3] and D. R. Spahn[1]

[1]Institute of Anaesthesiology, University Hospital Zurich, Raemistrasse 100, CH-8091 Zurich, Switzerland, [2]Department of Anaesthesiology, Thoraxklinik, Amalienstrasse 5, D-69126 Heidelberg, Germany and [3]Department of Biostatistics, University of Zurich, CH-8006 Zurich, Switzerland

**Corresponding author*

Oxygen saturation and carbon dioxide values should be monitored during high-frequency jet ventilation (HFJV). Modern transcutaneous P_{CO_2} (Ptc_{CO_2}) measurement allows the estimation of ventilation efficiency. We studied how tests of lung function could predict carbon dioxide elimination during HFJV. Lung function tests from 180 adult patients undergoing rigid bronchoscopy were analysed as factors affecting carbon dioxide elimination. The lung function test results showed a significant relationship with the efficiency of carbon dioxide elimination; the greatest impairment of carbon dioxide elimination was found in patients with combined abnormalities of lung function. Further factors associated with difficult carbon dioxide elimination were male gender and elevated body weight. Of the patients investigated, 72% had normal carbon dioxide elimination, whereas in 23% hypercapnia could be avoided only by increasing the driving pressure. The prevalence of abnormal preoperative lung function test results predicts (sensitivity 76%, positive predictive value 27%) impaired carbon dioxide elimination during jet ventilation and rigid bronchoscopy.

Br J Anaesth 2000; **84**: 635–7

Keywords: ventilation, jet; monitoring, carbon dioxide; anaesthetic techniques, bronchoscopy
Accepted for publication: January 5, 2000

High-frequency jet ventilation (HFJV) is a convenient method of ventilation during rigid bronchoscopy, since it offers optimal visibility and easy access for diagnostic and surgical instruments into the airway. However, monitoring of gas exchange is more difficult than during conventional ventilation and requires special equipment. We have recently described a new transcutaneous blood gas sensor prototype, the Sp_{O_2}-Ptc_{CO_2} ear probe (Linde Medical Instruments, Basel, Switzerland). This device provides reliable carbon dioxide partial pressure values compared with simultaneously determined Pa_{CO_2}, and has an *in vivo* latency period of 57±20 s.[1] Because of the speed and ease of use of this device, we now routinely use transcutaneous carbon dioxide measurement during HFJV as an approximation for Pa_{CO_2}. Since the jet driving pressure (DP) and the resulting transcutaneous PCO_2 (Ptc_{CO_2}) values are inversely related, we calculate a carbon dioxide elimination coefficient (Ec_{CO_2}) which helps to quantify the individual carbon dioxide elimination capacity under HFJV and under standardized conditions.[2]

A value of 1.0 results if Ptc_{CO_2} is normal (37.5 mm Hg) during jet ventilation with a moderate DP of 2.0 atm and represents a normal carbon dioxide elimination capacity. Reduced values indicate impaired carbon dioxide elimination. As an empirical cut-off value, we use an Ec_{CO_2} of 0.75 to differentiate between normal and compromised carbon dioxide elimination. We set out to assess the relation between preoperative lung function test results and carbon dioxide elimination during jet ventilation for rigid bronchoscopy.

Methods and results

After informed consent had been obtained, 180 adult patients of ASA physical status 1–4 who were scheduled for elective interventional rigid bronchoscopy under general anaesthesia and HFJV were included in this study. Vital capacity (VC) and forced expiratory volume in 1 s (FEV_1) were measured and compared with values predicted from standard equations.[3] A restrictive pattern was assumed if the measured VC was below 70% of the predicted value, and an obstructive abnormality if the measured FEV_1 was below 70% of the predicted value.

Total intravenous anaesthesia (TIVA) was conducted with propofol and remifentanil for induction and maintenance and succinylcholine for muscle relaxation. In addition to usual monitoring, continuous transcutaneous blood gas measurement with a calibrated Sp_{O_2}-Ptc_{CO_2} ear-clip sensor prototype (Linde Medical Instruments, Basel, Switzerland) was used.[1] Jet ventilation was performed with an AMS 1000 Universal Jet Ventilator- (Acutronic Medical Systems, Hirzel, Switzerland) via the rigid bronchoscope. A respiratory frequency of 150 cycles min^{-1} and an inspiration duration of 40% were set during the study. Therefore, the DP was the only variable in the HFJV setting.

The DP was set at 1.5, 2.0 and 2.5 atm for 5 min each, and the resulting Ptc_{CO_2} was documented 3 min after each change of DP setting. If oxygenation was poor (Sp_{O_2} <89%), HFJV was supplemented by manually assisted ventilation. Ec_{CO_2} values calculated at various DP settings were averaged. The physical and clinical characteristics of patients with normal carbon dioxide elimination were compared with those of patients with impaired elimination by the use of the Mann–Whitney test. The influence of lung function on Ec_{CO_2} was tested for dissimilarity by one-way analysis of variance (ANOVA). *Post hoc* comparisons of categories were performed using the Bonferroni–Dunn test. Frequencies were examined for variability by the chi-squared test; $P < 0.05$ was considered significant. In eight patients the Sp_{O_2} could not be maintained continuously above 89%, which prevented further analysis of carbon dioxide elimination under standardized study conditions. Thus, the data come from 172 patients. Ptc_{CO_2} values had a range of 24.8–66.8 mm Hg. One hundred and thirty-five patients had normal carbon dioxide elimination ($Ec_{CO_2} > 0.75$), and in 37 patients carbon dioxide elimination was compromised ($Ec_{CO_2} < 0.75$). Patients with compromised carbon dioxide elimination had a significantly greater body weight and a smaller VC and FEV_1, and the percentage of males was higher in this group of patients (Table 1).

Allocation of patients to the four prospectively defined patients the Sp_{O_2} could not be maintained continuously with normal lung function, (ii) 57 patients (33%) with obstructive abnormality, (iii) 22 patients (13%) with restrictive abnormality and (iv) 24 patients (14%) with combined (obstructive plus restrictive) abnormality. Elimination of carbon dioxide, as assessed by Ec_{CO_2}, was best in patients with normal lung function ($P = 0.0007$ in the overall ANOVA) and deteriorated progressively in patients with obstructive, restrictive and combined abnormality.

Normal values of lung function variables (VC and/or FEV_1) had a negative predictive value of 87% for normal carbon dioxide elimination ($Ec_{CO_2} > 0.75$), whereas the prevalence of at least one pathological lung function variable resulted in a positive predictive value of only 27% for compromised carbon dioxide elimination ($Ec_{CO_2} < 0.75$). Of patients with impaired carbon dioxide elimination ($Ec_{CO_2} < 0.75$), 76% had abnormal lung function tests (sensitivity) and normal results were present in only 44% of patients with normal carbon dioxide elimination ($Ec_{CO_2} > 0.75$) (specificity).

Table 1 Biometrical and clinical data during jet ventilation for rigid bronchoscopy in patients with normal and compromised carbon dioxide elimination. Frequencies were compared with the chi-squared test, the other variables with the Mann–Whitney test). Values are mean (SD). n.s. = not significant.

	Normal CO_2 elimination ($EC_{CO_2} > 0.75$)	Compromised CO_2 elimination ($EC_{CO_2} < 0.75$)	Statistical significance
Patients (*n*)	135	37	
Males (*n*)	82 (63%)	29 (76%)	$P<0.05$
Age (years)	58 (17–31)	59 (83–78)	n.s.
Height (cm)	171 (9)	171 (7)	n.s.
Weight (kg)	72 (13)	79 (15)	$P<0.05$
Predicted VC (l)	3.81 (0.87)	3.79 (0.65)	n.s.
Actual VC (l)	3.16 (0.96)	2.57 (0.93)	$P<0.05$
Predicted FEV_1 (l)	3.26 (0.77)	3.27 (0.55)	n.s.
Actual FEV_1 (l)	2.22 (0.78)	1.73 (0.73)	$P<0.05$
$FEV_1 \times 100/VC$ (%)	70.4 (12.9)	67.8 (15.3)	n.s.
Ventilation duration (min)	14 (11)	14 (7)	n.s.
Mean Ptc_{CO_2} (mm Hg)	40.8 (6.9)	52.4 (6.1)	$P<0.01$
Mean DP (atm)	1.9 (0.3)	2.3 (0.3)	$P<0.01$
Mean EC_{CO_2}	1.02 (0.18)	0.66 (0.08)	$P<0.01$
Lung function categories (*n*)			
Normal	60	9	$P=0.007$
Obstructive	48	8	
Restrictive	13	10	
Combined	14	10	

Comments

During HFJV the assessment of carbon dioxide status is a challenge. An arterial catheter may be not always indicated or feasible and capnography values may be invalid unless ventilation is interrupted regularly or special equipment is used. Recently introduced transcutaneous PCO_2 monitoring allows non-invasive and continuous carbon dioxide surveillance with a fair degree of precision and an acceptable response time.

The definition of a tolerable upper limit for Ptc_{CO_2} may be arbitrary; however, in the vast majority of patients, 50 mm Hg can be tolerated safely for the duration of a bronchoscopic intervention. Although in some cases even higher carbon dioxide values may be acceptable,[4] Ptc_{CO_2} values between 30 and 50 mm Hg are a reasonable routine target. If a Ptc_{CO_2} value of 50 mm Hg is an acceptable maximum while ventilating with a moderate DP of 2.0 atm, the resulting EC_{CO_2} must be above 0.75. Therefore, we used this as a cut-off value to divide the patients into two categories: 'normal' and 'compromised' carbon dioxide elimination.

The physical and clinical data show relevant differences between the two defined carbon dioxide elimination groups (Table 1). Male gender and high body weight are known to be associated with difficulty in achieving adequate gas exchange during HFJV, particularly with carbon dioxide elimination.[2 5 6] The same is true for abnormal lung function, but this depends on the type and degree of the abnormality. Surprisingly, obstructive lung disease, which is usually considered an important hindrance to carbon dioxide elimination during jet ventilation,[7 8] was less relevant than restrictive lung function. However, the preoperative abnormal lung function predicts difficult carbon dioxide elimination (sensitivity 76%) but normal results are not good predictors of normal carbon dioxide elimination during jet ventilation (specificity 44%).

In summary, most patients with abnormal pulmonary function tests undergoing rigid bronchoscopy (96%) can be ventilated adequately with HFJV. Measurement of lung function variables such as VC and FEV_1 and the prevalence of other cofactors, such as male gender and elevated body weight, can help to estimate the expected carbon dioxide elimination. Patients with normal carbon dioxide elimination will require a lower DP. This has the benefits of lowering airway pressure to the necessary minimum and reducing the adverse effects of HFJV, such as cooling and drying of the tracheobronchial epithelium.

Acknowledgements

The authors acknowledge the valuable contributions made to this investigation by H. D. Becker and F. Herth from the Section of Endoscopy, Thoraxklinik Heidelberg, Germany. We also wish to express our gratitude to Mr A. Tschupp of Linde Medical Instruments (Basel, Switzerland) for providing the cutaneous Sp_{CO_2}-Ptc_{CO_2} sensor prototype.

References

1 Rohling R, Biro P. Clinical investigation of a new combined pulse oximetry and carbon dioxide tension sensor in adult anaesthesia. *J Clin Monit* 1999; **15**: 23–7

2 Biro P, Eyrich G, Rohling R. The efficiency of CO_2 elimination during high-frequency jet ventilation for laryngeal microsurgery. *Anesth Analg* 1998; **87**: 180–4

3 Löllgen H. *Kardiopulmonale Funktionsdiagnostik*. Wehr/Baden: Ciba-Geigy, 1995

4 Stock C. Carbon dioxide and apnea: common knowledge and common sense. *J Clin Anesth* 1998; **10**: 181–3

5 Ayuso MA, Luis M, Sala X, Martinez G, Sanchez J, Alarcon A. Comparative study of high-frequency jet ventilation in 4 types of patients undergoing laryngeal microsurgery. *Rev Esp Anestesiol Reanim* 1997; **44**: 7–12

6 Lichtwarck-Aschoff M, Zimmermann GJ, Erhardt W. Reduced CO_2-elimination during combined high-frequency ventilation compared to conventional pressure-controlled ventilation in surfactant-deficient piglets. *Acta Anaesthesiol Scand* 1998; **42**: 335–42

7 Rouby JJ, Simonneau G, Benhamou D, *et al*. Factors influencing pulmonary volumes and CO_2 elimination during high-frequency jet ventilation. *Anesthesiology* 1985; **63**: 473–82

8 Bourgain J-L, McGee K, Cosset MF, Bromley L, Meistelman C. Carbon dioxide monitoring during high frequency jet ventilation for direct laryngosopy. *Br J Anaesth* 1990; **64**: 327–30